

Charging by Walking

Walking on an insulative floor covering produces a predictable charge.

There are very few cases in which it is possible to quantitatively describe an electrostatic charging process (i.e., the rate at which the voltage of an insulated conductive system or insulator field increases). Two important examples where this is possible, however, are the flow of a liquid such as gasoline into an insulated container or, of more interest in the electronics world, walking on an insulative floor covering—the most common way people are charged.



Niels Jonassen

As explained in a previous column titled "Is Static Electricity Static?" (CE January/February 2000), the charging of a person by walking can be described by assuming that the contact and friction between the person's shoe soles and the floor separates a charge, Δq , for each step.¹ If the step rate is n steps per unit of time, this corresponds to a charging current of

$$i_c = n\Delta q. \quad (1)$$

The current will charge the person in such a way that the voltage, V , will initially increase at a mean rate of

$$\frac{\Delta V}{\Delta t} = \frac{n\Delta q}{C}, \quad (2)$$

where C is the person's capacitance. The increase in voltage,

ΔV , by the first step will be

$$\Delta V = \frac{\Delta q}{C}. \quad (3)$$

The voltage will cause a decay current, i_d , through the resistance, R , from the person to ground:

$$i_d = \frac{V}{R}. \quad (4)$$

And the voltage will reach its maximum value, V_m , when $i_c = i_d$ or

$$V_m = Rn\Delta q. \quad (5)$$

If the highest acceptable body voltage is V_{accep} , then the grounding resistance must fulfill the condition

$$R \leq \frac{V_{accep}}{n \cdot \Delta q_{max}}, \quad (6)$$

where Δq_{max} is the maximum value of the charge separated per step.

In the column cited, the maximum value of Δq_{max} was estimated as

$$\Delta q_{max} = \epsilon_0 E_b A, \quad (7)$$

where ϵ_0 (the permittivity of air) = $8.85 \cdot 10^{-12} \text{ F} \cdot \text{m}^{-1}$, E_b (the breakdown field strength in air between plane electrodes) $\approx 3 \cdot 10^6 \text{ V} \cdot \text{m}^{-1}$, and A (the area of the shoe sole) $\approx 150 \text{ cm}^2$ (see Figure 1). Introducing these values into Equation 5, we find that

$$\Delta q_{max} \approx 4 \cdot 10^{-7} \text{ C}, \quad (8)$$

which corresponds to a charging

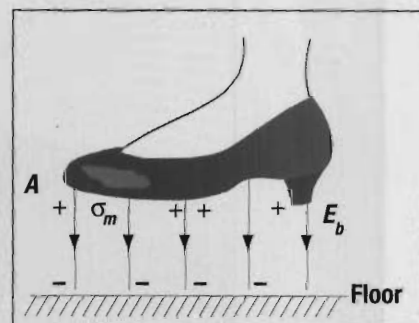


Figure 1. Charge separation between shoe and floor.

current of

$$i_{c,max} = n \cdot \Delta q_{max} = 8 \cdot 10^{-7} \text{ A} \approx 10^{-6} \text{ A}, \quad (9)$$

assuming a rate of 2 steps/sec. Therefore, if $V_{accep} = 100 \text{ V}$, then $R \leq 100 \text{ M}\Omega$. Note that the values for an acceptable floor resistance derived from Equations 6 and 9 are conservative. It is highly unlikely that the whole area of the shoe sole would be charged to the breakdown level and that no neutralizing discharge would occur when lifting the foot.

Equation 3 indicates the expected increase in voltage at the first step to be

$$\Delta V = \frac{4 \cdot 10^{-7}}{100 \cdot 10^{-12}} = 4 \text{ kV}, \quad (10)$$

assuming a capacitance of 100 pF for one foot. To find more realistic values for Δq and ΔV , a series of measurements of the body voltage on a highly insulative floor covering (vinyl tiles) were taken. The body resistance to ground was measured to $10^{11} \Omega$, varying over the floor from 0.5 to $1.5 \cdot 10^{11}$

Mr. Static

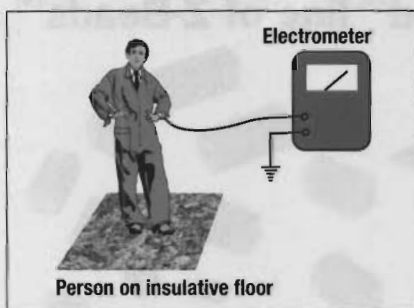


Figure 2. Measurement of body voltage.

Ω . The body capacitance was 160 pF for both feet and 100 pF for one foot.

The experimental setup is shown in Figure 2. The person is connected to an electrometer, which can be run as a charge meter (high capacitance) or as a static voltmeter (low capacitance). With the meter in the charge-measuring mode, the charge for a single step was determined. As the average of 10 determinations, the value was found to be

$$\Delta q = 3 \cdot 10^{-8} \text{ C}, \quad (11)$$

with a standard deviation on a single determination of $0.5 \cdot 10^{-8} \text{ C}$. According to Equation 3, this corresponds to a voltage increase for the first step of

$$\Delta V = \frac{3 \cdot 10^{-8}}{100 \cdot 10^{-12}} = 300 \text{ V}. \quad (12)$$

With a rate of 2 steps/sec, Equation 5 indicates an expected maximum voltage of

$$V_m = Rn\Delta q = 10^{11} \cdot 2 \cdot 3 \cdot 10^{-8} = 6 \text{ kV}. \quad (13)$$

Figure 3 shows the body voltage as a function of time. It appears that the voltage reaches a maximum of about 3.5 kV after approximately 15 seconds. The reason a person doesn't reach the predicted maximum value of 6 kV from Equation 13 can be found in the decay curve starting at 21 seconds. At that moment, the person stands still and allows the charge to be neutralized through the effective grounding resistance. An analysis of the curve shows that the initial decay corre-

sponds to a resistance of approximately $2 \cdot 10^{10} \Omega$ and concludes with a value close to $10^{11} \Omega$. This must mean that the resistance (or rather, the resistivity) of the floor (and sole) material decreases with increasing voltage (or rather, field strength). The direct

The resistivity of the floor material decreases with increasing field strength.

measurement of the person's resistance was taken at a voltage of approximately 300 V, and the measured resistance will therefore be higher than the effective resistance at the maximum voltage.

The value of V_m predicted by Equation 5 appears to provide a safe upper limit for the body voltage when walking on a floor characterized by a resis-

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tance R . One problem, however, remains. According to Equation 3, the voltage developed by a single (the first) step seems to be independent of the decay resistance. Further, the value of 300 V, as predicted by Equation 12, could be a problem in many scenarios involving electrostatic discharge. It should also be stressed that Equation 3 does not account for the unavoidable decay during the time it takes to lift the foot from the floor and separate the charge Δq . If this time is Δt , then the voltage ΔV at the end of Δt can be written as

$$\Delta V = \frac{\Delta q}{C} \cdot \frac{RC}{\Delta t} \left(1 - e^{-\frac{\Delta t}{RC}} \right) \quad (14)$$

If we assume $\Delta t \approx 0.1$ second, C (one foot) = 100 pF, $n = 2$ steps/sec, and $\Delta q = 3 \cdot 10^{-8}$ C, we can find ΔV (Equation 14) and V_m (Equation 5) as functions of the decay resistance R (see Figure 4). It appears that for low values

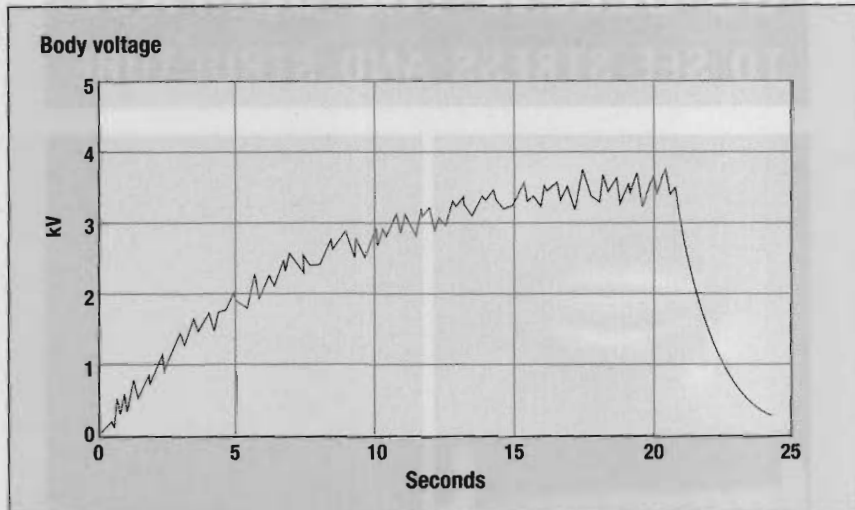


Figure 3. Body voltage of person walking on an insulative floor.

of R , ΔV is higher than V_m . For instance, at $R = 10^9 \Omega$ (1 G Ω) the mean maximum voltage is $V_m = 60$ V, and the one-step voltage is $\Delta V = 180$ V. It may seem peculiar that the body voltage after one step (rather, at the end of the first foot lift) can be higher than the

mean body voltage after many seconds. The reason is that the voltage decays in the time between the lifting of one foot and the lifting of the other foot. Assuming $\Delta t = 0.1$ second and $n = 2$ steps/sec, this decay time is approximately 0.4 second (i.e., four times as

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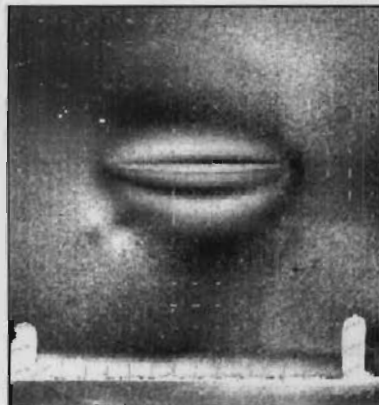
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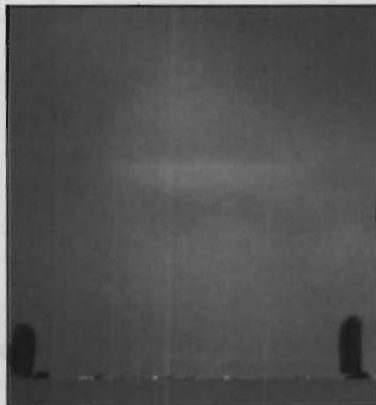
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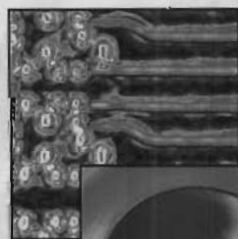


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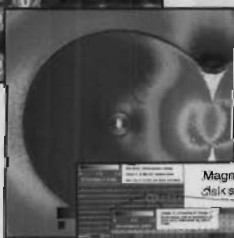
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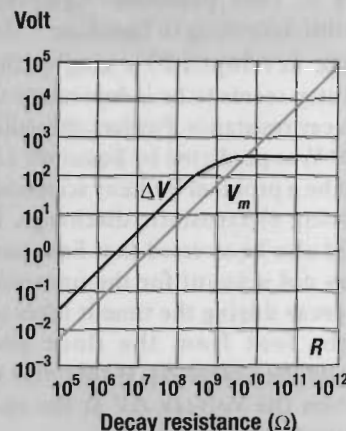


Figure 4. Maximum voltage, V_m , and one-step voltage, ΔV , as a function of the decay resistance, R .

long as the charging time).

The curves show that $\Delta V = V_m = 270$ V at $R = 4.5 \cdot 10^9 \Omega$. The implication of the results plotted in Figure 4 is that at resistances lower than approximately 4.5 G Ω , the voltage spikes connected with a single step are the primary concern, and at higher resistances the equilibrium voltage integrated over many steps is the dominating factor.

Conclusion

The upper limit of the voltage to which a person walking across an insulative floor may be charged can be predicted with reasonable accuracy by measuring the person's total resistance to ground. And again, at relatively low resistances ($< \text{ca. } 4.5 \text{ G}\Omega$) the body voltage after one step shows up as a voltage spike higher than the mean body voltage integrated over several steps.

Reference

1. Niels Jonassen, "Is Static Electricity Static?" in Mr. Static, *Compliance Engineering* 17, no. 1 (2000): 30-36.

Niels Jonassen, MSc, DSc, worked for 40 years at the Technical University of Denmark, where he conducted classes in electromagnetism, static and atmospheric electricity, airborne radioactivity, and indoor climate. He is now officially retired and divides his time among the laboratory, his home, and Thailand, writing on static electricity topics and pursuing cooking classes. He can be reached at mr.static@scientist.com. ■